CHAPTER 5
COASTAL PROTECTION

5-1. Shoreline stabilization.

a. Methods. The shoreline stabilization methods can be generally classified as artificial nourishment and protective construction.

(1) *Artificial nourishment.* The artificial nourishment methods include the following:

(a) *Offshore dredging.* The material dredged elsewhere is deposited in a ridge offshore and updrift of the beach to be stabilized.

(b) *Stockpiling.* A beach is placed updrift, but not offshore, of the denuded area from which material is derived for replenishment of the downdrift area.

(c) *Continuous supply.* A pumping plant located on the updrift jetty at a harbor entrance bypasses the sand across the inlet to the eroding shore.

(d) *Direct placement.* This method is a variation on the use of a stockpile in that the fill is completed at one time over the entire area to be protected.

(2) *Protective construction.* The following protective structures may be used for shoreline stabilization:

(a) *Breakwaters.* Breakwaters reduce the wave force reaching the shore. Offshore breakwaters are more costly than onshore structures and are seldom built solely for shore protection, rather they are constructed mainly for navigational purposes. A breakwater protecting a harbor area provides shelter for all types of marine vessels.

(b) *Jetties.* Jetties are generally employed at inlets in connection with navigation improvements. They control sand movement and shoaling in channels. Jetties are similar in structure though larger than groins and sometimes extend from the shoreline seaward to a depth equivalent to the channel depth desired for navigation purposes.

(c) *Groins.* Groin is a barrier-type structure that extends from the backshore into the littoral zone. The basic purposes of a groin are to interrupt longshore sand movement, to accumulate sand on the shore, or to retard sand losses.

(d) *Shoreline armoring.* Bulkheads, seawalls, and revetments are wave-resistant walls used to armor the shore and provide a definite landwater boundary at a given location. The distinction between seawalls, bulkheads, and revetments is mainly a matter of purpose. In general, seawalls are the most massive of the three because they resist the full force of the waves. Bulkheads are next in size; their function is to retain fill, and they are generally not exposed to severe wave action. Revetments are the lightest because they are designed to protect shorelines against erosion by currents or light wave action.

b. Selection of basic stabilization method.

(1) *Artificial nourishment.*

(a) *Advantage.* The artificial supply benefits not only the shoreline where it is placed but other shores as well.

(b) *Disadvantages.* Temporary changes in the shoreline due to individual storms are not prevented by artificial nourishment. The method is not suitable for stabilization of areas abutting buildings, pavements, or other structures. Also, the amount of supply must be balanced against the amount of decretion. An oversupply causes accretion, which may be detrimental; an inadequate supply will be ineffective in producing the desired stability.

(2) *Protective construction.*

(a) *Advantages.* Protective structures require little maintenance as compared to the continuing supply requirement involved in the use of artificial nourishment. Furthermore, the results are more positive than with the use of artificial nourishment.

(b) *Disadvantage.* In the highly developed areas, correction of localized deficiencies is not feasible. In such areas, protective structures must be installed over an extensive length of shoreline because their use in one location tends to produce decretion in adjacent downdrift areas.

c. Layout and design for stabilization by artificial nourishment. After the selection of artificial nourishment as the method of shoreline stabilization, layout and design can take into account the following factors: (1) Rate of loss of beach material. The loss rate may be measured by one of the following methods: (a) Measure the quantity of littoral current and the solid content of the suspended sediments. Use the difference in quantity between the updrift and downdrift ends of the site.

(b) Take beach-profiles over a period of time and determine the loss rate by section.

(c) Approximate the loss rate from aerial photography or maps of changes in the shoreline. Use the rule that a loss of 1 square foot of surface area represents a loss of 1 cubic yard of beach material. This rule has been found applicable for exposed seacoasts; for less exposed shores, it results in a conservative approximation.

(2) *Direction of littoral drift.* Determine the direction of littoral drift from these or similar observations: (a) Major accumulations of sediment at existing jetties and groins.

(b) Hindcast wave data refracted into shallow water.

(c) Shore patterns in the vicinity of headlands.

(d) Characteristics of beach and bed materials.

(e) Current measurements.

(3) Beach material. Select suitable material considering the following factors:

(a) Use clean sand. Some clay or silt admixtures are permissible; particles will be sorted by natural wave action.

(b) Proper gradation is required to produce the desired slope. The gradation should be the same as that of materials found on nearby beaches having slopes similar to those desired.

(4) *Crest height.* Match the existing beach crest or that of nearby beaches similarly exposed.

(5) *Miscellaneous.*

(a) The rate of supply of artificial nourishment must balance the rate of loss from an existing beach.

(b) Locate the stockpile of artificial nourishment updrift of the problem area. Do not place the toe of the stockpile in water depths exceeding 20 feet on seacoasts.

(c) Offshore dumping may be used. Deposits have been successfully made up to 0.5 mile offshore and in water depths up to 38 feet.

d. Sand bypassing system. A sand bypassing system consists of a stationary hydraulic-suction dredge pump, which dredges sand from the updrift side of an inlet and pumps it across the inlet channel, usually through a subaqueous pipe. The pump installation is usually at the head of the updrift jetty. Floating installations are possible but not desirable except under unusual circumstances. The design details are as follows: (1) Position the discharge pipe so that the sweep of the current will distribute the sand along the problem area.

(2) Govern the required discharge velocity with median grain-size sand.

(3) Provide auxiliary equipment for clearing a clogged discharge pipe, such as compressed air jets, complete with compressors, pumps, and tanks.

5-2. Waves and wave pressures.

a. Individual wave characteristics. Waves generated in deep water (generally considered as water having a depth > L/2, where L is the wavelength) are normally identified as the oscillatory type, in which particles of water oscillate in a circular pattern about some mean position. In shallow water, the particle paths are

elliptical rather than circular. Primary characteristics of individual waves are shown in figure 5-1. For the normal deepwater wave, the various wave characteristics are related by the following equations:

$$v = 2.26 \sqrt{L} = 5.12T \qquad (5\text{-}1)$$
$$L = 0.195v^2 = 5.12T^2 \qquad (5\text{-}2)$$
$$T = 0.442 \sqrt{L} = 0.195v \qquad (5\text{-}3)$$

where
v = velocity of propagation of wave, feet per second
L = wavelength, feet T = wave period, seconds

b. Tsunamis and hurricane surge.

(1) Tsunamis are very long-period waves (usually 5 to 30 minutes in period) that are caused by a displacement of the ocean bottom due to seismic activity. Ports around the entire Pacific Ocean are susceptible to tsunami waves; however, the effects at different harbors vary considerably due to the local bathymetry from the continental slope shoreward and to the direction of approach by the tsunami. Ports and harbors bordering the Atlantic Ocean have practically no problem from tsunamis due to the lack of active seismic regions around the periphery of the Atlantic Basin.

(2) Hurricane surge (or typhoon surge) is more common than tsunami surge and presents a problem on the East and Gulf Coasts of North and Central America, the Eastern and Southeastern Coasts of Asia, and islands in that area of the Pacific. The occurrence of hurricanes and typhoons is fairly well documented (especially in the United States), and the frequency of occurrence of various intensity hurricanes and the resulting waves and hurricane surge can be calculated. It would be considerably beneficial to the site selection process to catalog all existing data on hurricanes and typhoons to assess the probability of port downtime for each year; and the probability of extensive damage from both hurricane surge and winds.

c. Explosion-generated water waves. Explosion-generated water waves exhibit the same characteristics as any waves produced by a local disturbance in deep water. A train of waves is generated where the maximum amplitude wave always has the same period (regardless of distance of propagation). The amplitude of this wave decreases as 1/R (R being the distance propagated from the source). If the explosion occurs in shallow water, the first wave is usually the largest, regardless of propagation distance, due to a very slow rate of dispersion. The amplitude and frequency of the largest wave are functions of the explosion yield, height or depth of burst, distance from the explosion, water depth, and bottom topography. An explosion is an inefficient method of generating water waves and a relatively large-yield nuclear explosion is required to create waves of appreciable height. The area affected   by

explosion-generated waves is extremely localized when compared with the several-hundred-mile-wide area affected by a tsunami. The periods of nuclear-explosion-generated waves can roughly be classified as being between that of wind waves and tsunami waves, i.e., they are in the long-period wave region but can have amplitudes considerably greater than those of normal long-period waves found in the open ocean.

d. Design wave calculation.

(1) For preliminary study and/or structures where occasional damage may be permissible. One of the following procedures may be used:

(a) Refer to local records and experiences of longtime residents.

(b) Make observations at the site of such physical features as wash and runup marks and debris.

(c) Use the following empirical relations for open seas and inland lakes.

Open seas (Stevenson formula)

$$H = 1.5\sqrt{F} \text{ for } F > 30 \text{ nautical miles} \qquad (5\text{-}4)$$

or

$$H = 1.5\sqrt{F} + 2.5 - \sqrt[4]{F} \text{ for } F < 30$$
nautical miles $\qquad (5\text{-}5)$

Inland lakes (Molitor formula)

$$H = 01.17\sqrt{UF} \text{ For } F > 20 \text{ nautical miles} \qquad (5\text{-}6)$$

or

$$H = 0.17\sqrt{UF} + 2.5 - \sqrt[4]{F} \text{ for } F < 20$$
nautical miles $\qquad (5\text{-}7)$

where
H = wave height, feet
F = fetch, nautical miles
U = maximum wind velocity, miles per hour

(*d*) Where the wind speed is known and an adequate fetch for full development of the waves is assumed, equation (5-8) may be used for waves of low to moderate amplitude. This formula is not applicable to very high waves (more than 25 to 30 feet).

$$H = 0.026U^2 \qquad \qquad 5\text{-}8)$$
where U represents wind velocity in knots.

(*e*) When the maximum wind velocity, as well as the fetch, is known, a more accurate determination of the design wave is possible using figures 5-2 through 5-13.

(2) *For final design of structures of major importance.* For such design or where the extent of the development warrants more accurate determination of the wave characteristics, follow the procedures given below:

(*a*) Make an analysis of a comprehensive series of aerial photographs of the incident waves generated by severe storms.

(*b*) Hindcast (i.e., calculate from historic, synoptic weather charts) the characteristics of waves resulting from several of the more recurrent deepwater storms. Determine the shallow-water characteristics of these waves by use of refraction and diffraction diagrams. The determination of the characteristics of the incident waves by hindcasting is the most reliable method for determining the design wave. Detailed wave and water level predictions are given in "Shore Protection Manual," Vol. 1. (See app A.)

e. Wave pressure on vertical walls. Wave pressures due to breaking and nonbreaking waves differ widely. The first step in the evaluation of wave forces is to determine if the structure will be subjected to forces from nonbreaking waves, breaking waves, or broken waves. The determination of wave pressure on vertical walls is explained in "Shore Protection Manual," Vol. II. (See app A.)

f. Wave forces and movements on piles. Waves acting on piles exert pressures that are the result of drag and inertial forces. The determination of waves forces and movements on piles can be found in "Shore Protection Manual," Vol. II. (See app A.)
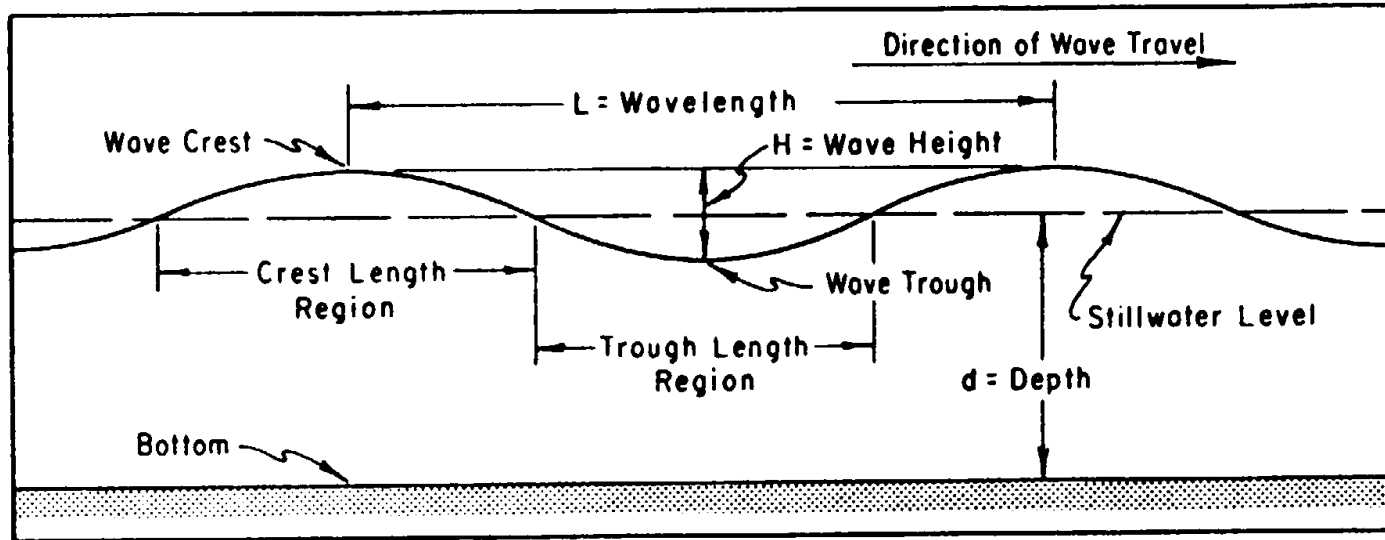
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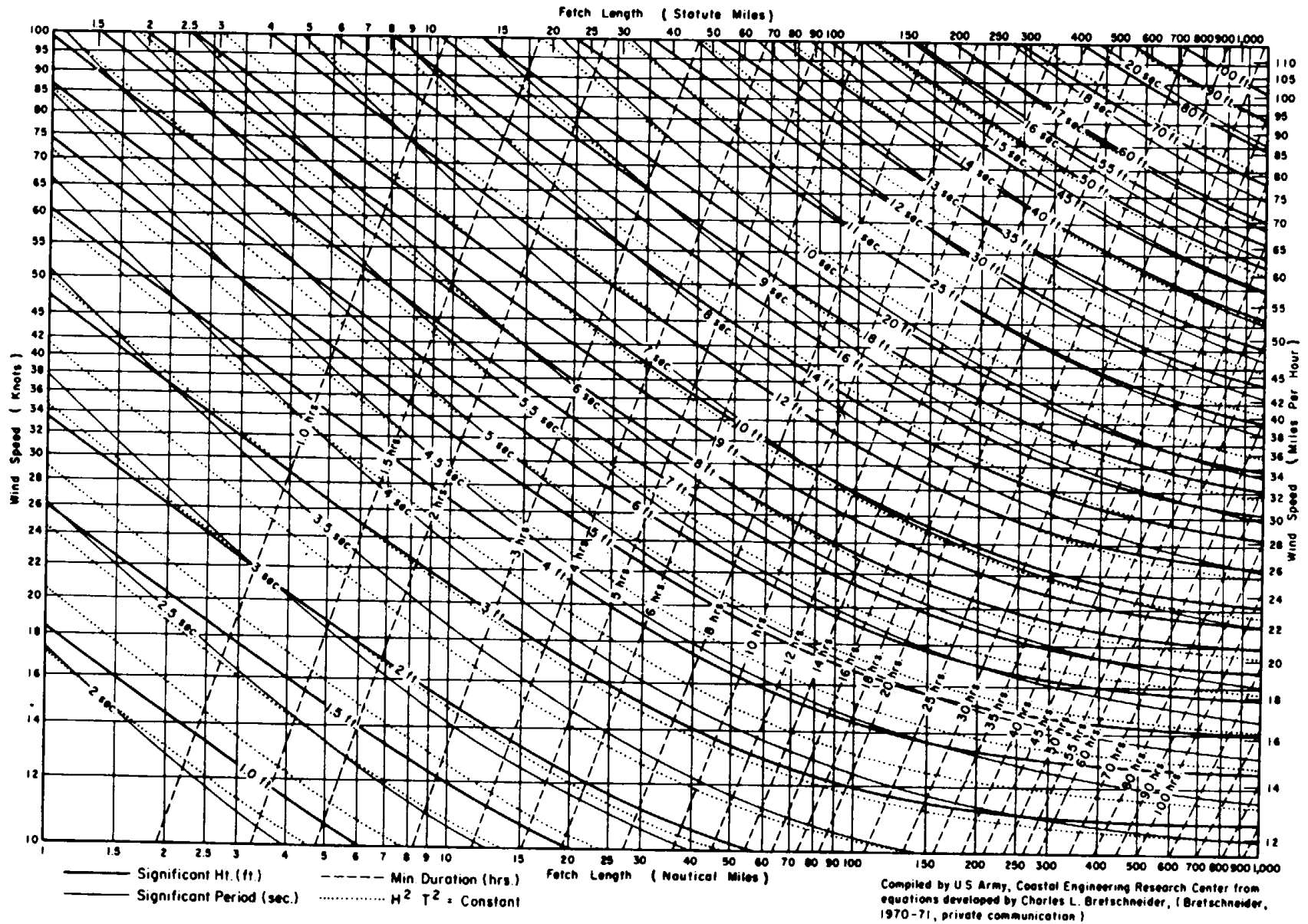*Figure 5-1. Wave Characteristics.*

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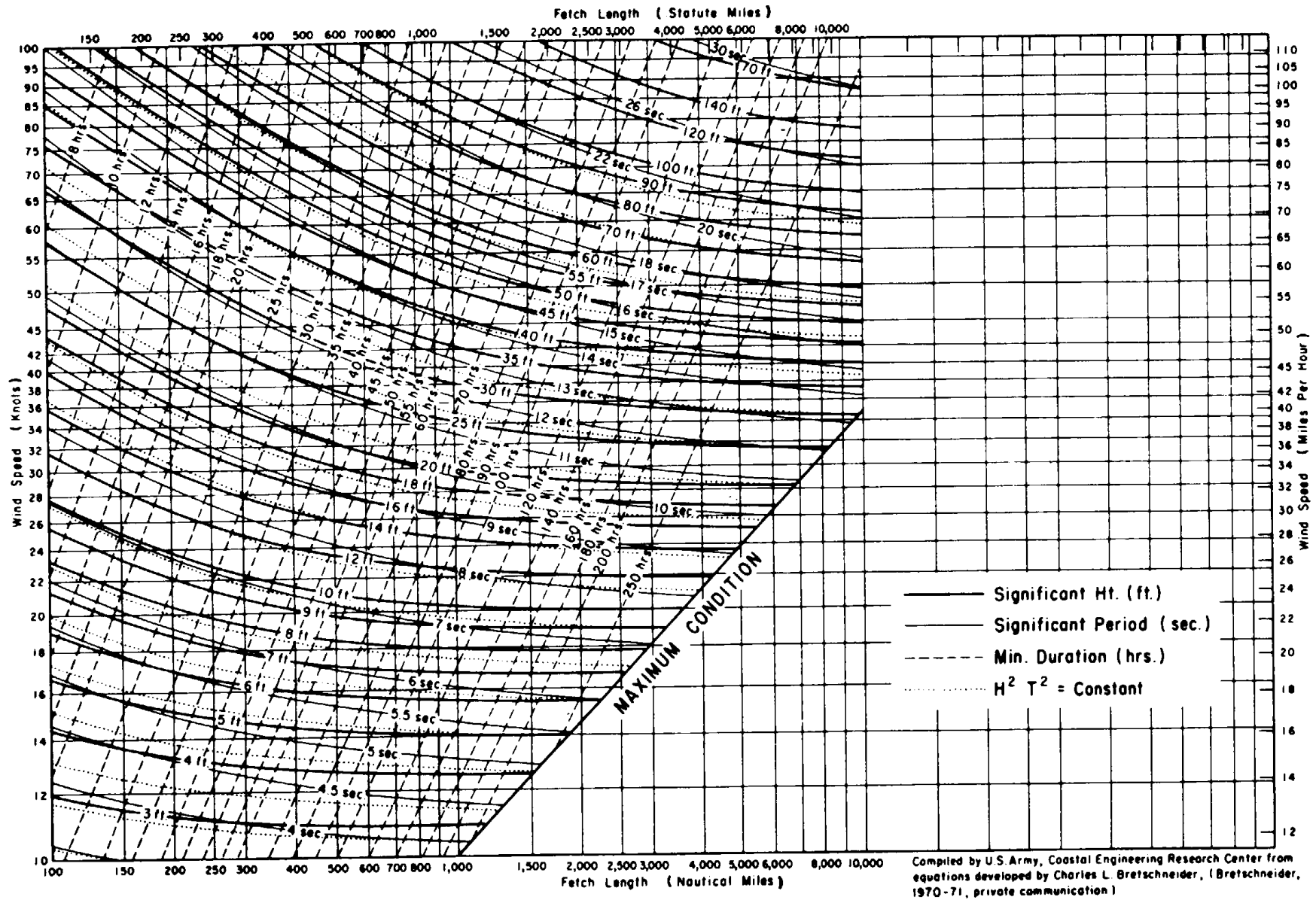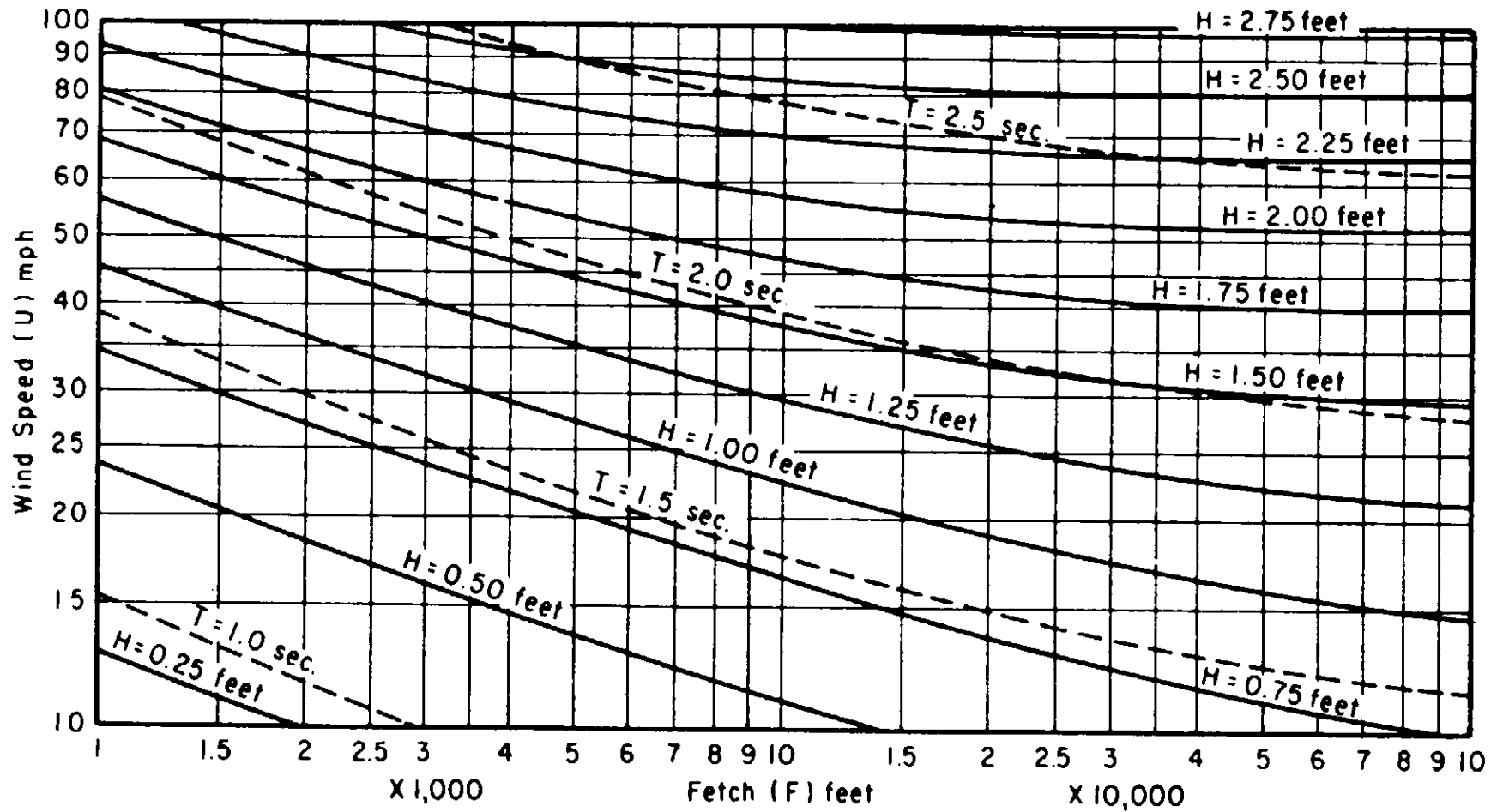Figure 5-2. Deepwater wave forecasting curves (for fetches of 1 to 1,000 miles).

Figure 5-3. Deepwater wave forecasting curves (for fetches of 100 to more than 1,000 miles)
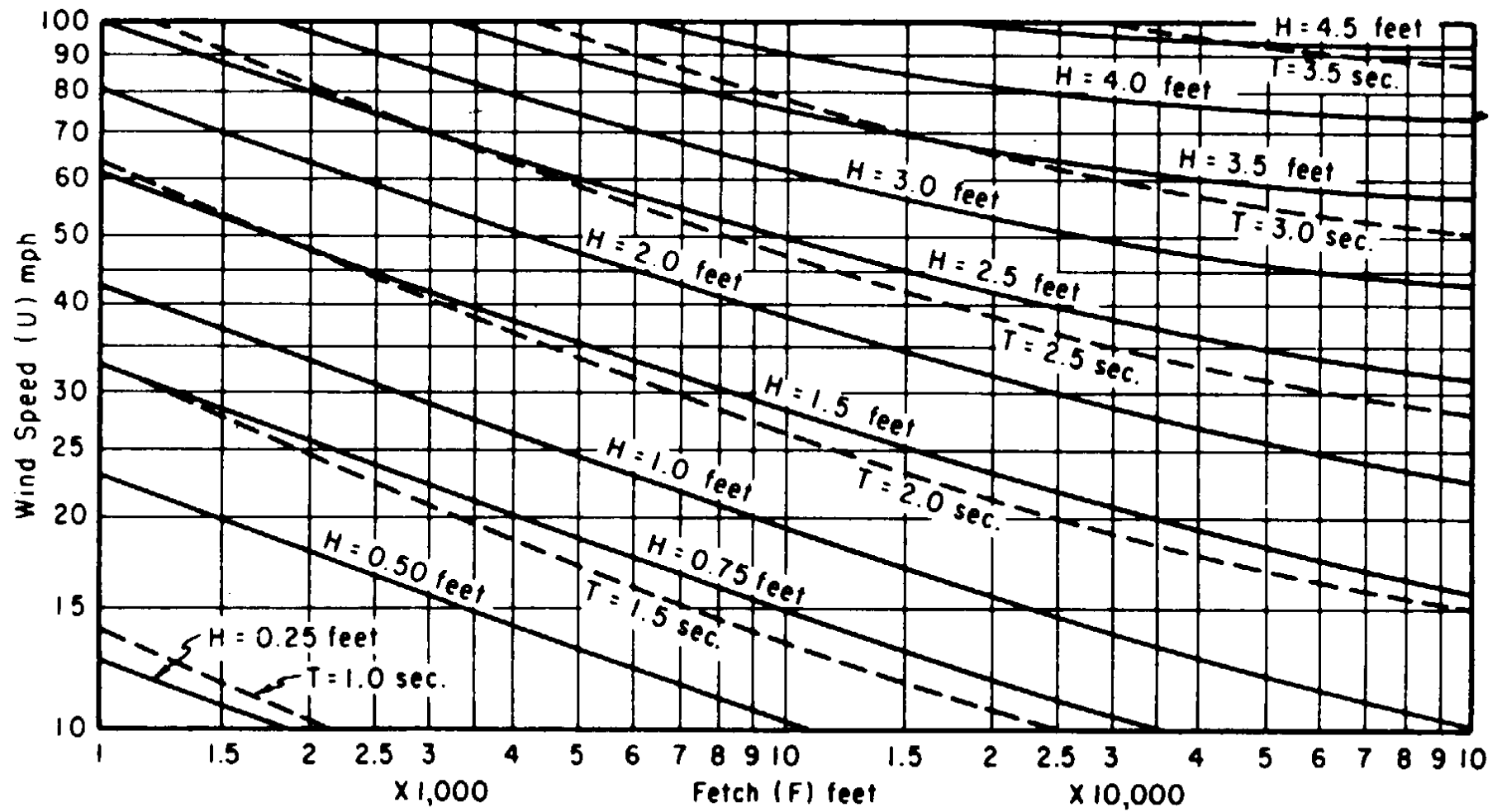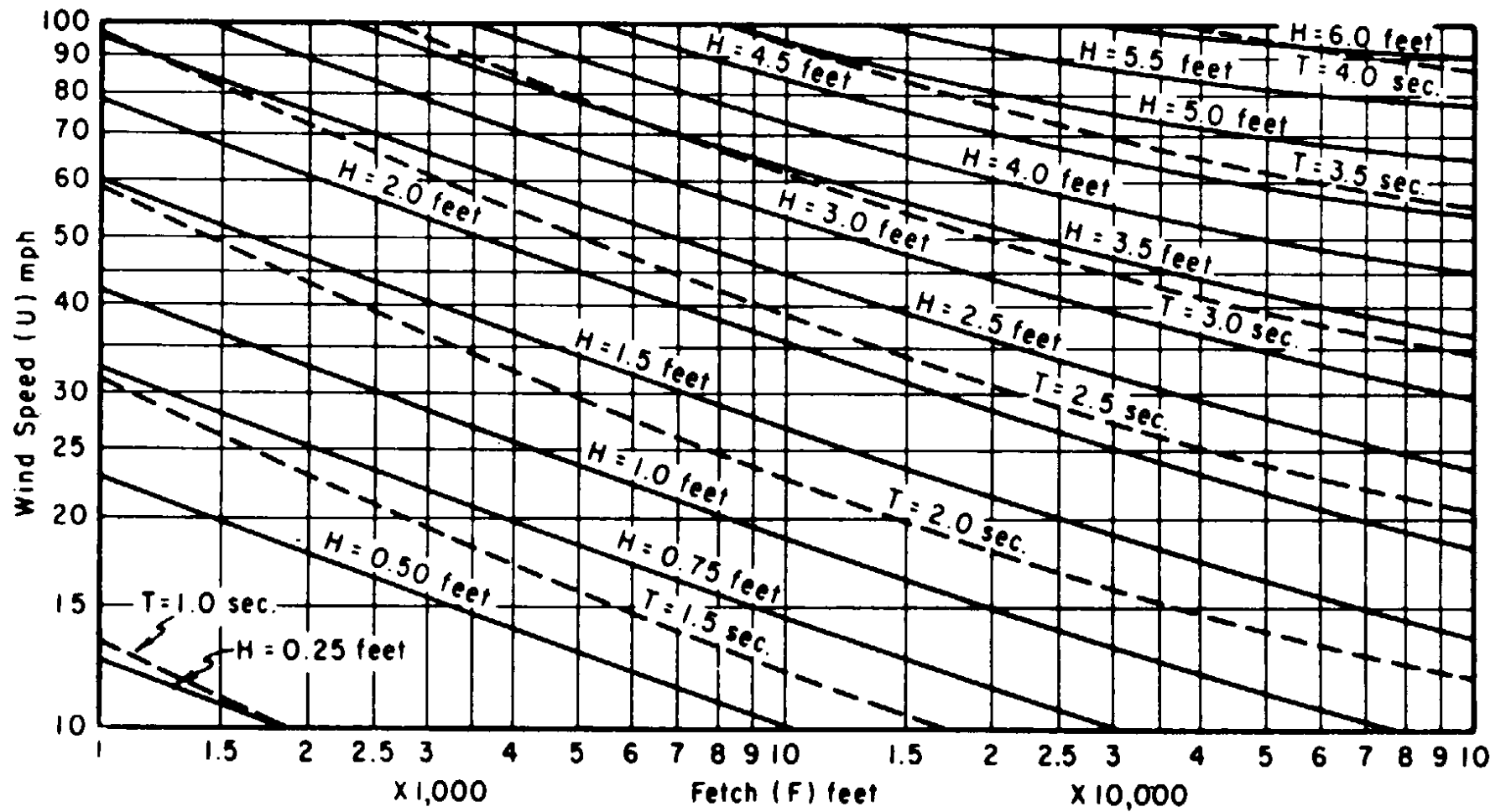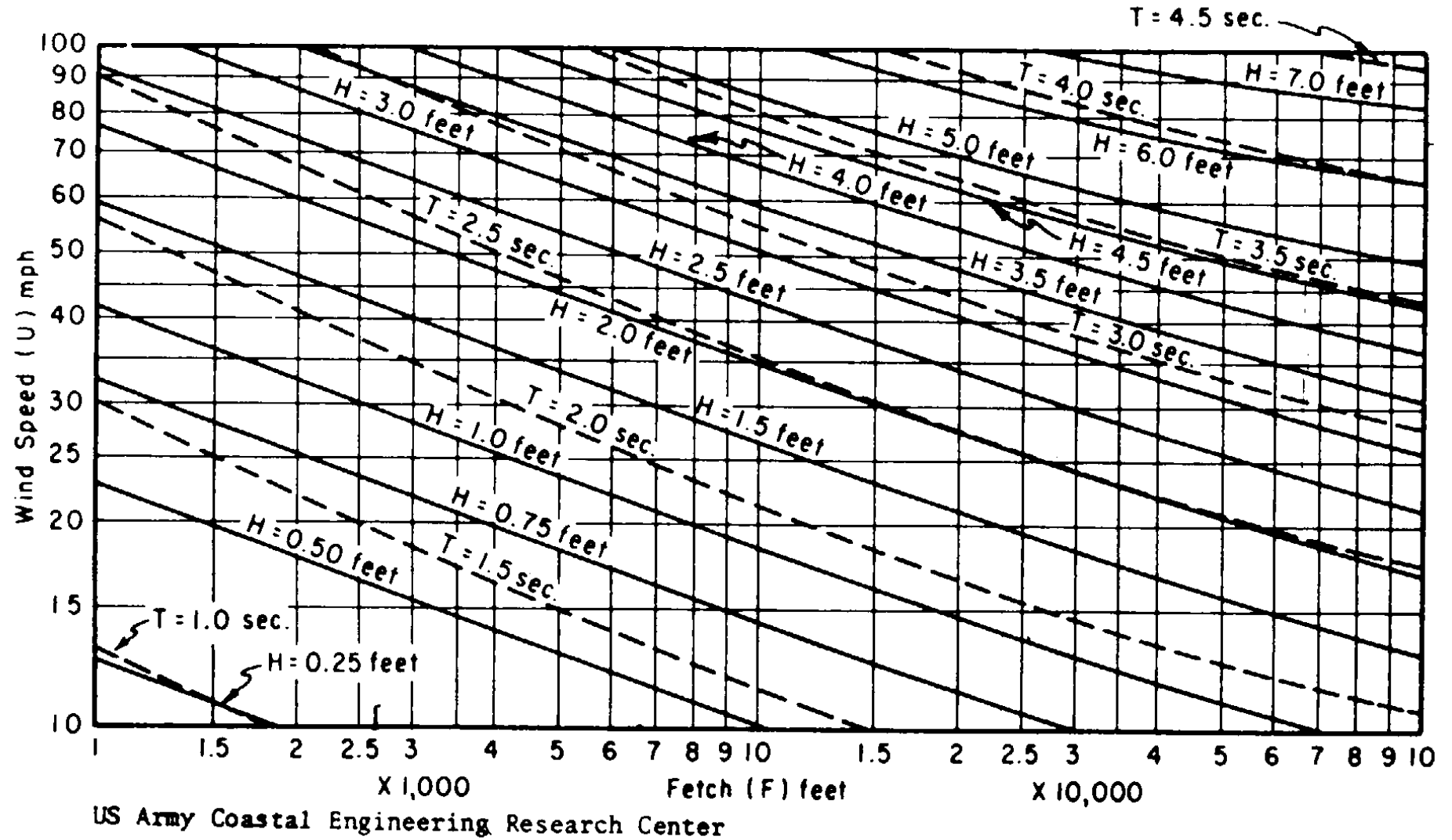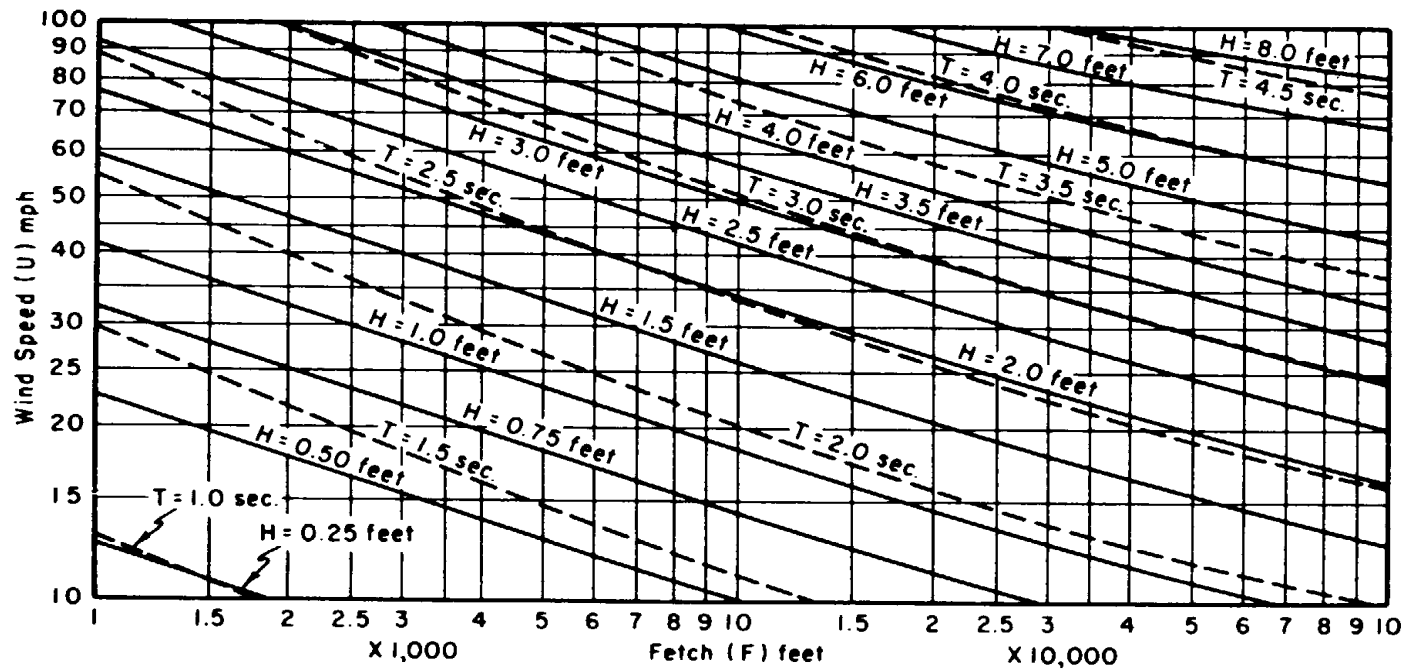
Figure 5-4. Forecasting curves for shallow-water waves (constant depth = 5 feet).

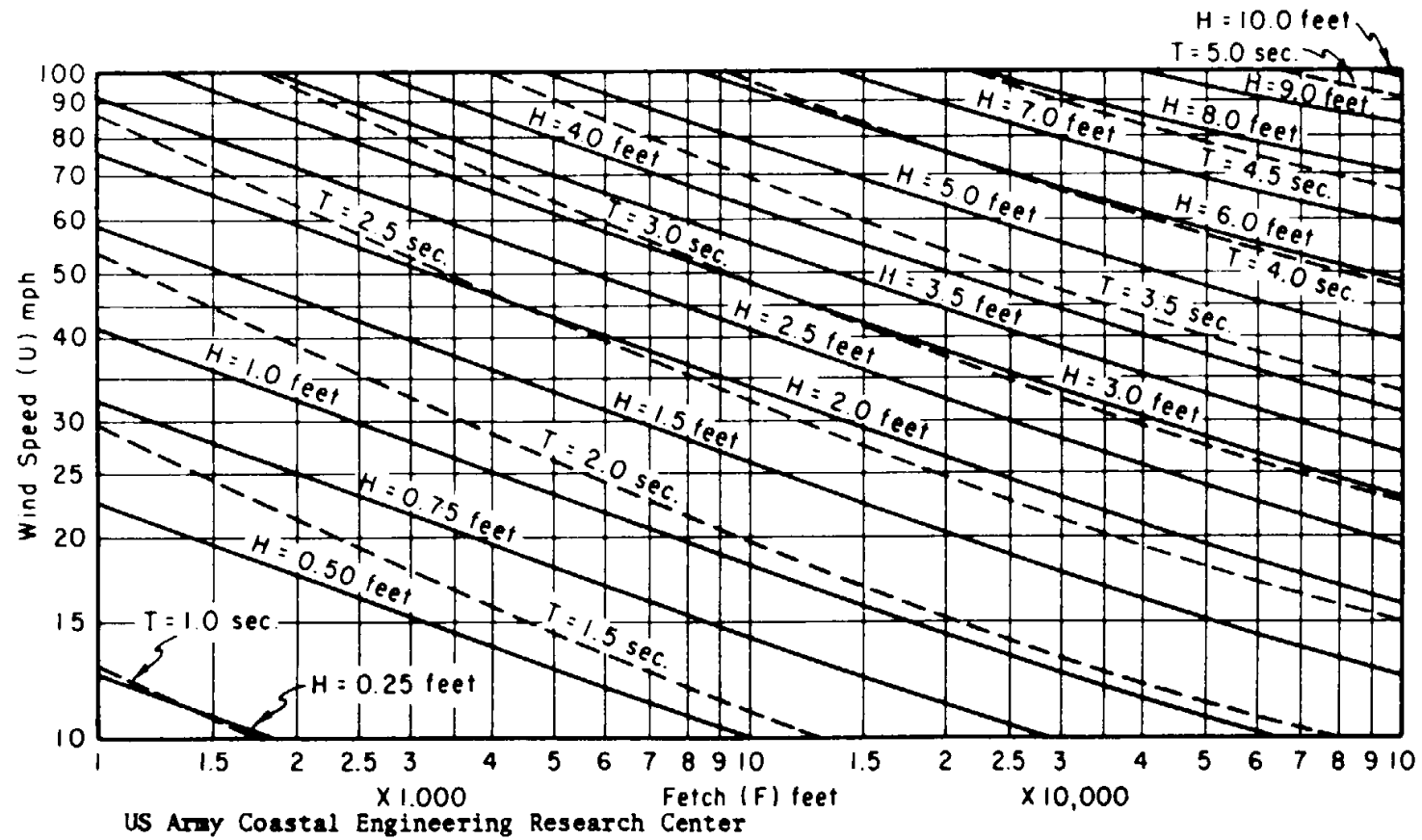US Army Coastal Engineering Research Center

Figure 5-5. Forecasting curves for shallow-water waves (constant depth = 10 feet).

Figure 5-6. Forecasting curves for shallow-water waves (constant depth = 15 feet).

Figure 5-7. Forecasting curves for shallow-water waves (constant depth = 20 feet).
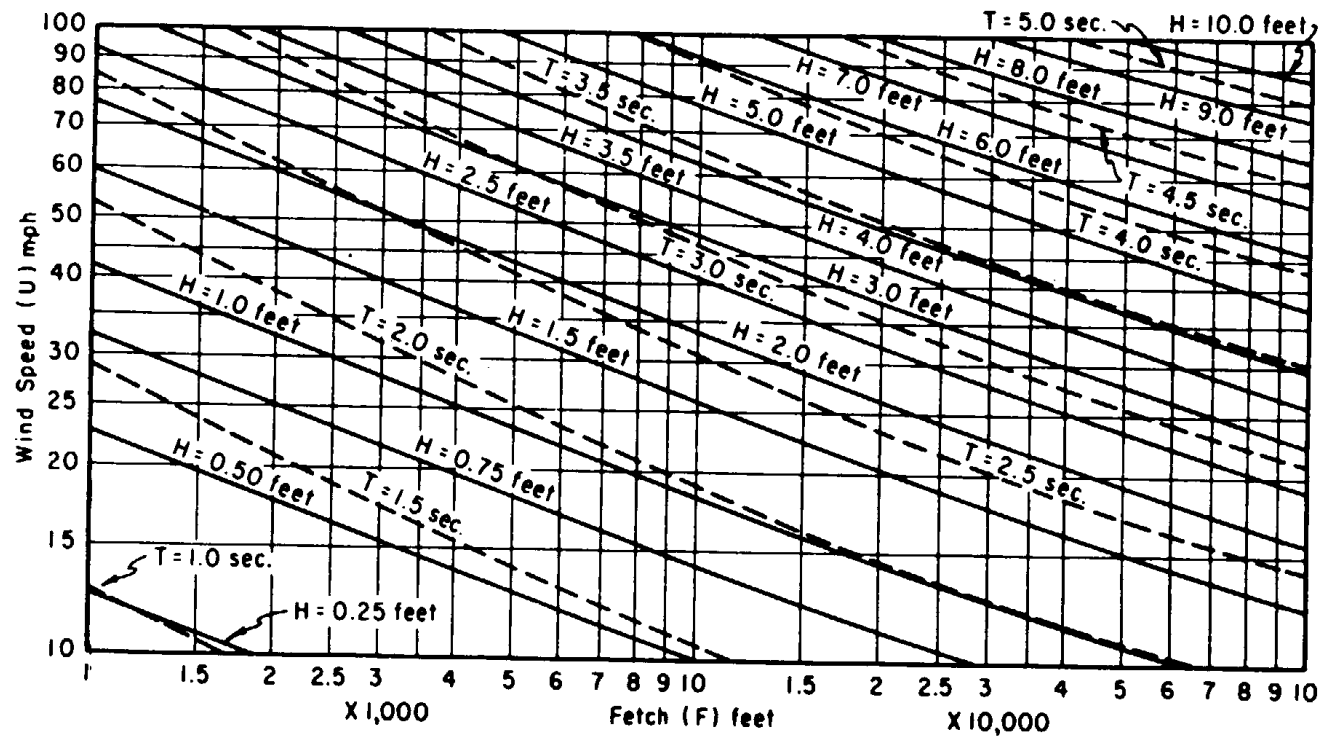
Figure 5-8. Forecasting curves for shallow-water waves (constant depth = 25 feet).

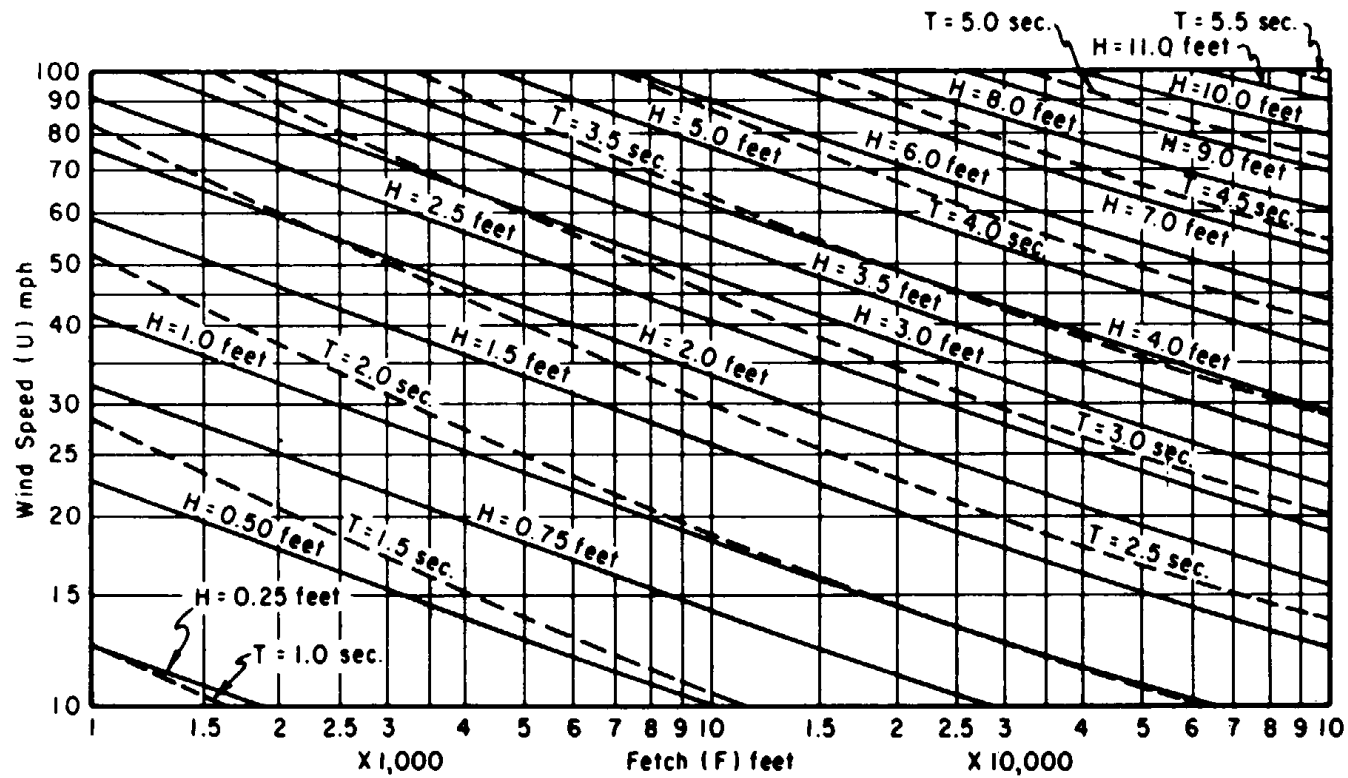*Figure 5-9. Forecasting curves for shallow-water waves (constant depth = 30 feet).*

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Figure 5-10. Forecasting curves for shallow-water waves (constant depth = 35 feet).

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Figure 5-11. Forecasting curves for shallow-water waves (constant depth = 40 feet).
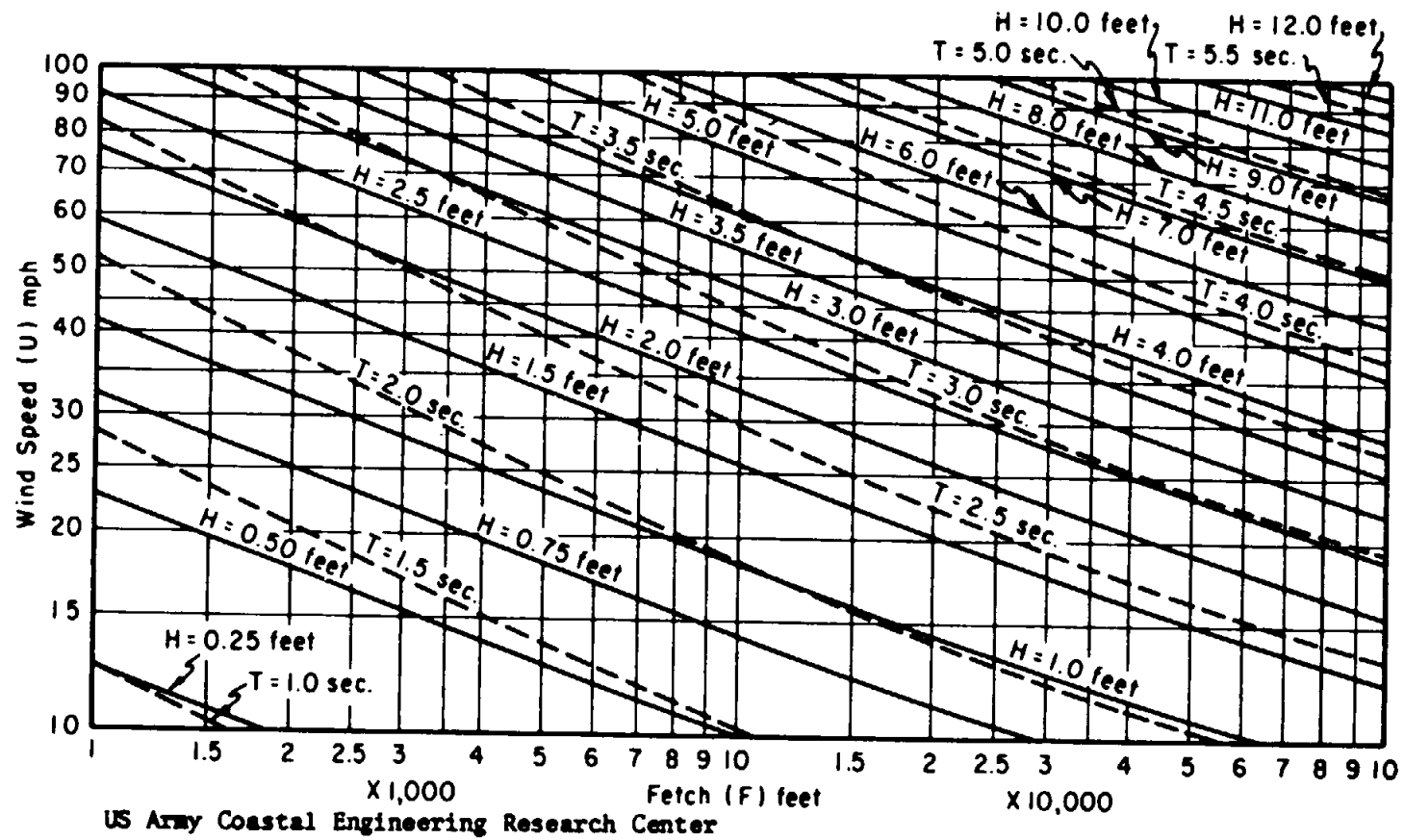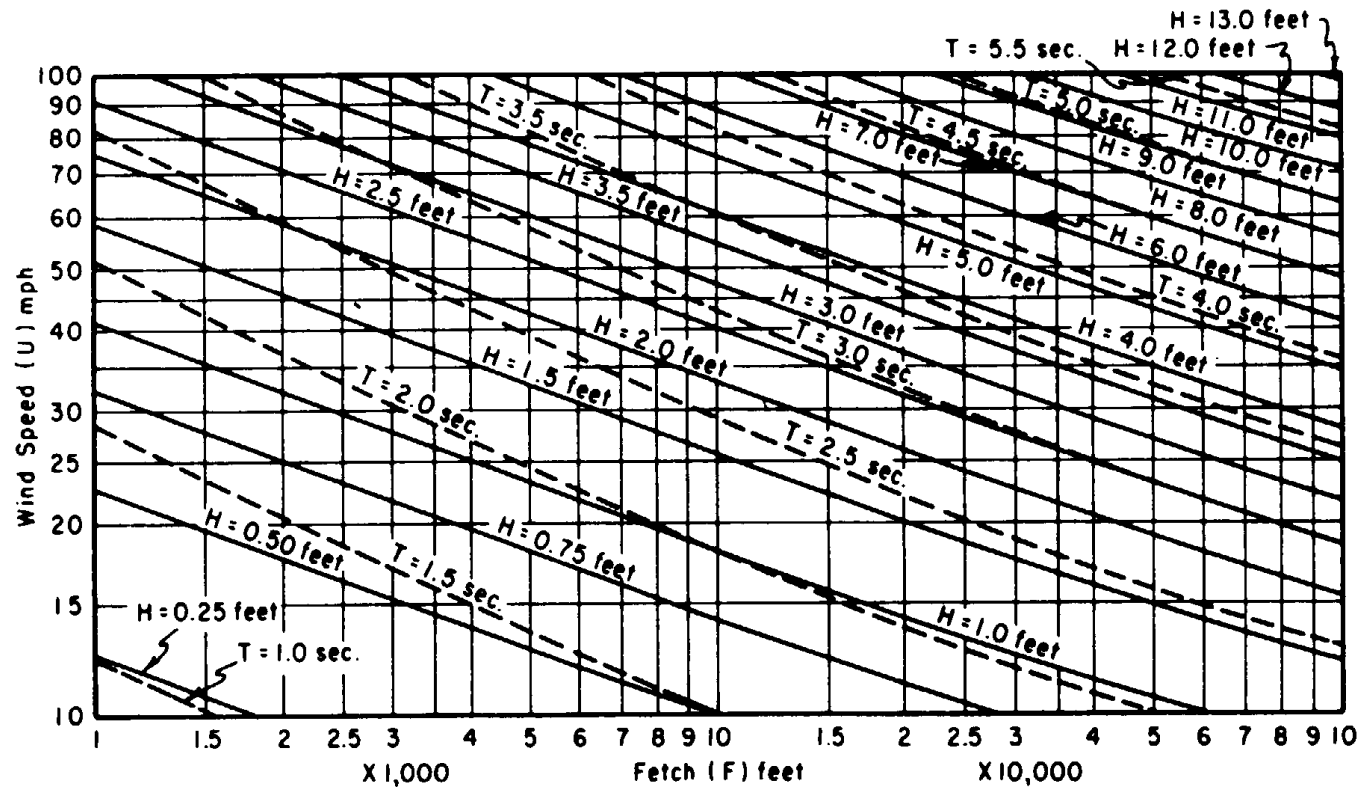
5-14

Figure 5-12. Forecasting curves for shallow-water waves (constant depth = 45 feet).

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Figure 5-13. Forecasting curves for shallow-water waves (constant depth = 50 feet).

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